

**NAS5-97066 Final Report  
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**FINAL PROGRESS REPORT FOR ASTROPYSICS DATA PROGRAM  
CONTRACT NAS5-97066  
by S. Terebey, Extrasolar Research Corp.**

Final Progress report for the astronomy research proposal entitled "The Contribution of Ionizing Stars to the Far-Infrared and Radio Emission in the Galaxy"

by Dr. S. Terebey (PI), Extrasolar Research Corp., Pasadena CA,  
Dr. M. Fich (co-I), Dept. of Physics; Univ of Waterloo, Waterloo CAN  
Dr. R. Taylor (co-I), Dept. of Physics and Astronomy; Univ. of Calgary,  
Penticton CAN

**FINAL SUMMARY Report of Work Jan 1997 THROUGH Dec 1999**

**Abstract**

S. Terebey summarizes research activities carried out in this eighth and final progress report. The final report includes: this summary document, copies of three published research papers, plus a draft manuscript of a fourth research paper entitled "The Contribution of Ionizing Stars to the Far-Infrared and Radio Emission in the Milky Way; Evidence for a Swept-up Shell and Diffuse Ionized Halo around the W4 Chimney/Supershell," by authors S. Terebey, M. Fich, R. Taylor, and Y. Cao. The main activity during the final quarterly reporting period was research on W4, including analysis of the radio and far-infrared images, generation of shell models, a literature search, and preparation of a research manuscript. There will be additional consultation with co-authors prior to submission of the paper to the Astrophysical Journal. The results will be presented at the 4th Tetons Summer Conference on "Galactic Structure, Stars, and the ISM" in May 2000.

In this fourth and last paper we show W4 has a swept-up partially ionized shell of gas and dust which is powered by the OC1 352 star cluster. Analysis shows there is dense interstellar material directly below the shell, evidence that the lower W4 shell "ran into a brick wall" and stalled, whereas the upper W4 shell achieved "breakout" to form a Galactic chimney. An ionized halo is evidence of Lyman continuum leakage which ionizes the WIM (warm ionized medium). It has long been postulated that the strong winds and abundant ionizing photons from massive stars are responsible for much of the large scale structure in the interstellar medium (ISM), including the ISM in other galaxies. However standard HII region theory predicts few photons will escape the local HII region. The significance of W4 and this work is it provides a direct example of how stellar winds power a galactic chimney, which in turn leads to a low density cavity from which ionizing photons can escape to large distances to ionize the WIM.

**Scientific Description**

The main product of this work has been the production of the IRAS Galaxy Atlas (IGA), its characterization, and research using the IGA to understand large scale structure in the diffuse interstellar medium in the Milky Way. The IGA was produced on a parallel supercomputer at Caltech, using the MCM resolution enhancement algorithm developed in-house to produce high spatial resolution images of the Galactic plane at infrared wavelengths from the IRAS data (InfraRed Astronomical Satellite).

The first research paper resulting from this contract is "The High-Resolution IRAS Galaxy Atlas," by Y. Cao, S. Terebey, T. A. Prince, and C. A. Beichman, published in the Astrophysical Journal Supplement Series, 1997, v111, p387-408. This paper describes the production, verification, and characterization of the IGA so that it can be used for scientific research by the general astronomical community.

One of the important uses of the IGA is to study physical processes in the interstellar medium, because much of the visible structure is from ISM dust which is heated by starlight. To further the value of ISM research with the IGA, a collaboration was established with two other groups producing Galactic plane surveys at other wavelengths with similar ~1 arcminute resolution: the DRAO radio-wave Canadian Galactic Plane Survey (CGPS) and the CO millimeter-wave survey from FCRAO/University of Massachusetts. The three groups coordinated efforts to first observe and share data in the so-called pilot region, encompassing the W3, W4, and W5 HII regions in the outer Galaxy.

The second research paper describes a multiwavelength study of large-scale Galactic structure in the pilot region, entitled "The Anatomy of the Perseus Spiral Arm: 12CO and IRAS Imaging Observations of the W3-W4-W5 Cloud Complex," by M. Heyer and S. Terebey. The results of that paper show that molecular clouds and star formation are strongly confined to the spiral arm, and rules out several theories for molecular cloud formation. The paper shows that molecular clouds do not survive in between spiral arms. Furthermore most of the ISM dust is strongly heated by UV photons from massive stars in W3-W4-W5 star forming regions, in contrast to the extended infrared cirrus seen elsewhere in our Galaxy.

The third research paper describes an improved mathematical algorithm for producing high spatial resolution images from IRAS data. The algorithm minimizes the "ringing" artifact which is very common in resolution enhancement techniques. This algorithm was not developed in time for production of the IGA. The IGA contains only 60 and 100 micron wavelength images, but not 12 and 25 microns where point sources (and ringing) dominate the structure. The improved algorithm was published in the paper entitled "Cross Burg Entropy Maximization and Its Application to Ringing Suppression in Image Reconstruction," by Y. Cao, P. Eggermont, and S. Terebey in the IEEE Transactions on Image Processing, 1999, v8, p286-292.

The fourth paper is a preliminary manuscript which describes a detailed case-study of the W4 region which shows how massive stars in a young star cluster inject energy into the ISM through strong winds and strong radiation fields. The paper is entitled "The Contribution of Ionizing Stars to the Far-Infrared and Radio Emission in the Galaxy: Evidence for a Swept-up Shell and Diffuse Ionized Halo around the W4 Chimney/Supershell," by authors S. Terebey, M. Fich, R. Taylor, and Y. Cao.

The main activity during the final quarterly reporting period was research on W4, including analysis of the radio and far-infrared images, generation of shell models, a literature search, and preparation of a research manuscript.

1. Resolution matched IRAS and DRAO images were constructed. Software was written in IDL to measure spatial resolution, and to compute the necessary gaussian beam matching kernel. Images were convolved to generate sets of images with the same spatial resolution. Set 1: IRAS 60 micron and DRAO 21 cm and 74 cm continuum. Set 2: IRAS 60 micron and 100 micron.

2. The IRAS dust temperatures were derived across the W4 image. There is a hot spot in the temperature map at the position of the IC1805 cluster which conclusively shows the cluster stars are indeed responsible for heating the surrounding dust. Elsewhere in the W4 shell the derived dust

temperature is nearly constant, measuring 37K +/- 2K. The near uniform temperature suggests Lyman alpha heating of dust, a theoretical effect which this data nicely supports. The temperature map was constructed in a series of stages. Step 1- A model for the background emission was generated by making integrated 21 cm line images and multiplying by the HI to IRAS 100 conversion given in Terebey and Fich 1986, Astrophysical Journal Letters, vol 309, p73. This background model was subtracted from the IRAS 60 and 100 micron images, to remove structure unrelated to W4. Step 2- flux ratio maps were constructed from the beam-matched IRAS 60 micron and 100 micron. Step 3- the dust temperature was derived for each pixel, using an algorithm which color-corrected the IRAS data.

3. An optical depth map was derived using the IRAS 100 micron image and the previously derived dust temperatures. Typical optical depths are several by  $10^{-4}$ , which show the optical depth is small at 100 microns as expected. The optical depth image clearly shows there is dense interstellar material directly below the W4 shell; the detection of this dense gas and dust supports the hypothesis that the lower half of the W4 supershell "ran into a brick wall" and stalled, whereas the upper half achieved "breakout", forming a Galactic chimney.

4. Quantitative models were made for the postulated dust and gas shell using IDL. The models were then compared with the IRAS images and the DRAO radio images. The total derived mass in the dust shell is about 10,000 solar masses. The interior of the shell is ionized with a derived total ionized gas mass of about 3600 solar masses.

5. Other physical parameter were derived including electron density, neutral gas density, infrared luminosity, and fraction of ionizing photons which escape the shell. The derived properties of the partially ionized shell were compared with a theoretical model for W4 chimney by Basu, Johnstone, and Martin (1999, Astrophysical Journal ).